APPLICATION FOR UNITED STATES LETTERS PATENT

FOR

FACIAL CHARACTERISTIC BASED GENERATION OF FILLET WELD BEAD REPRESENTATION

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Facial Characteristic Based Generation of Fillet Weld Bead Representation

BACKGROUND

5   Advances in computing technology have made possible the provision of computer-aided-design (CAD) software to support the design and manufacturing of articles. Modern CAD software not only includes sketching or schematic features, but also solid modeling and other advanced features.

          Manufacturing of articles often involves the welding of two or more
10   components of an article into one single piece. A variety of welding types may be employed, including what is referred to as fillet welds. Accordingly, it is desirable for CAD software to support modeling of welding, in particular, fillet welding.

          A few commercial CAD systems offer support for representing welds.
15   Externally, the support includes highlighting and/or labeling of the edges of the components involved. Alternatively, some CAD systems generate a solid representation of the bead. However, the method in which the highlighting/labeling of the edges is done or how the solid bead is generated is not known fully.

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BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention will be described referencing the accompanying drawings in which like references denote similar elements, and in which:

Figure 1 illustrates a computing environment incorporated with one embodiment of the present invention;

Figures 2a-2b illustrate two examples of computing environments of **Fig. 1**;

Figure 3 illustrates an example machine readable article having instructions implementing all or portions of the CAD application of **Fig. 1**;

Figure 4 illustrates one embodiment of the overall operational flow of the weld bead modeling function of **Fig. 1** in relation to modeling fillet welds;

Figure 5 illustrates one triangular profile embodiment of the operational flow in further detail;

Figure 6 illustrates one embodiment of a triangular profile;

Figure 7 illustrates one quadrilateral profile embodiment of the operational flow in further detail;

Figure 8 illustrates one embodiment of a quadrilateral profile;

Figure 9 illustrates an example transfer of profile attributes to lateral faces in a tool generated by sweeping a profile along a path;

Figure 10 illustrates one embodiment of the operational flow for generating a blank;

Figure 11 illustrates one embodiment of the operational flow for generating a path;

Figure 12 illustrates one embodiment of the operational flow for generating a trimmer body;

Figures 13a-13d illustrate an example application of one embodiment of the present invention;

Figures **14a-14e** illustrate an example application of one embodiment of the present invention; and

Figures **15a-15f** illustrate an example application of one embodiment of the present invention.

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DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

Embodiments of the present invention include, but are not limited to, methods to model/represent fillet welds in a computing environment, instructions implementing or contributing to the implementation of the

5 methods, components, devices and systems incorporated with one or more implementations.

In the following description, various aspects of embodiments of the present invention will be described. However, it will be apparent to those skilled in the art that embodiments of the present invention may be practiced

10 with only some or all aspects described. For purposes of explanation, specific numbers, materials and configurations are set forth in order to provide a thorough understanding of these embodiments of the present invention. However, it will be apparent to one skilled in the art that various embodiments of the present invention may be practiced without the specific details. In other

15 instances, well-known features are omitted or simplified in order not to obscure the disclosed embodiments of the present invention.

Various operations will be described as multiple discrete operations in turn, in a manner that is helpful in understanding these embodiments of the present invention, however, the order of description should not be construed

20 as to imply that these operations are necessarily order dependent. In particular, these operations need not be performed in the order of presentation.

The phrase "in one embodiment" is used repeatedly. The phrase generally does not refer to the same embodiment, however, it may. The

25 terms "comprising", "having" and "including" are synonymous, unless the context dictates otherwise.

Referring now to **Figure 1** wherein a computing environment incorporated with one embodiment of the present invention is illustrated. As

shown, for the embodiment, computing environment **100** includes CAD

application **112**, having associated user interface **102** and data

representations **122**. CAD application **112** includes a number CAD functions,

in particular, weld bead modeling function **114** and shape manager **116**. The

5   various CAD functions, including weld bead modeling function **114** and shape

manager **116** are equipped to create, process and delete various data

representations **124** of articles of manufactures, including data

representations **126** of their components and edges, and data representations

128 of weld beads. Resultantly, articles of manufactures may be modeled

10   and displayed **104** in user interface **102**, including their components, edges

and weld beads, **106** and **108**.

Except for weld bead modeling function **114**, CAD application **112**

including shape manager **116** represent a broad range of these elements.

For example, CAD application **112** may be implemented based on Inventor 7

15   (also referred to as Autodesk Inventor Series) product available from

Autodesk Inc. of San Rafael, CA.

In alternate embodiments, CAD application **112** including shape

manager **116** may be implemented with other CAD applications with an

integral geometric modeler, or other CAD applications employing a

20   complementary standalone geometric modeler instead.

Similarly, data representations **122** may be implemented in a variety of

manners, including but are not limited to link lists, relational tables, and other

data organizations/structures of the like. Likewise, user interface **102** may be

implemented in any one of a number of manners, in particular, a graphical

25   manner.

Figure 2a illustrates one embodiment of computing environment **100** of

Fig. 1. As illustrated, for the embodiment, computing environment **100** is a

computing device **200** incorporated with one embodiment of the present

invention. More specifically, computing device **200** includes processor **202**, memory **204**, mass storage device **206** and other I/O devices **208**, coupled to each other via bus **210**, as shown.

Memory **204** and mass storage device **206** include a transient working

5   copy and a persistent copy of CAD application **112**, including associated user interface **102** and data representations **122** of **Fig. 1**. Further, for the embodiment, memory **204** and mass storage device **206** include a transient working copy and a persistent copy of operating system **222**, providing a number of system services to CAD application **112**.

10   Processor **202**, memory **204**, mass storage **206**, I/O devices **208**, and bus **210** represent a broad range of such elements.

In other words, except for CAD application **112** endowed with weld bead modeling function **114**, computing device **200** represent a broad range of such devices, including but are not limited a server, a desktop computer, a

15   computing tablet, a laptop computer, a palm sized personal assistant, a pocket PC, or other computing devices of the like.

Figure 2b illustrates another embodiment of computing environment **100** of **Fig. 1**. As illustrated, for the embodiment, computing environment **100**

20   is a networked computing environment **250** including client device **252** and server **256** coupled to each other via network **254**.

Collectively, client device **252** and server **256** are equipped with an embodiment of CAD application **112**, including associated user interface **102** and data representations **122**. In other words, CAD application **112**, including

25   associated user interface **102** and data representations **122** are distributively disposed on client device **252** and server **256**. In various embodiments, client device **252** and server **256** may be computing device **200** of **Fig. 2a**.

Similarly, network **254** represents a broad range of local area, wide area, private and/or public networks. An example of a public network is the Internet.

5   **Figure 3** illustrates a machine readable article suitable for use to store executable instructions implementing all or portions of the CAD application **112** of **Fig.1**, including weld bead modeling function **114**, in accordance with one embodiment. For the embodiment, the machine readable article includes storage medium **300** and instructions implementing all or portions of a CAD
10   application **112**, including weld bead modeling function **114**, stored therein. The stored instructions may be used to program an apparatus, such as computing device **200** of **Fig. 2a**, or client device **252** and/or server **254** of **Fig. 2b**.

In various embodiments, storage medium **300** may be a diskette, a
15   tape, a compact disk (CD), a digital versatile disk (DVD), a solid state storage device, or other electrical, magnetic and/or optical storage device of the like.

Figure 4 illustrates one embodiment of the overall operational flow of weld bead modeling function **114** of **Fig. 1** in relation to modeling fillet welds.
20   The embodiment assumes CAD application **112** includes the functions for facilitating entry into a welding modeling mode of operation, where on entry, weld bead modeling function **114** is invoked. Further, CAD application **112** includes the functions for facilitating selection of the faces of the components of an article of manufacture involved in a particular fillet welding operation to
25   fillet weld the components of the article together during manufacturing. For example, CAD application **112** may include support to facilitate a user in making the selection using a cursor control device, such as a mouse, trackball, a touch pad and so forth. The support may leverage user input device services provided e.g. by operating system **222**.

Still referring to **Fig. 4**, as illustrated, on selection, weld bead modeling

function **114** first examines predominantly the geometric characteristics of the

selected faces of the selected components, block **402**. In various

embodiments, the geometric characteristics may include, but are not limited

5   to,

- whether the selected faces to be fillet welded have "simple" geometry

such as whether a selected face is planar or a selected face is

cylindrical, and so forth,

- whether the selected faces of a selected component lie on a single

10   plane, and

- whether two corresponding faces of the selected components are

perpendicular.

Next, for the embodiment, weld bead modeling function **114** selects a

generation technique to generate a data representation to model a fillet weld

15   bead, based at least in part on the result of the examination, block **404**. For

ease of understanding, hereinafter, the description may simply be presented

referring to various generation operations as generating a fillet weld bead or

other physical entities, without repeatedly qualifying the various generation

operations as generating data representations or models of the fillet weld

20   bead or other physical entities (as opposed to the physical entities

themselves). Thus, for the purpose of the present application, unless the

context clearly indicates to the contrary, the phrases "generating a fillet weld

bead", "generating a data representation of a fillet weld bead", "generating a

model of a fillet weld bead", and other phrases of the like, are to be

25   considered as synonymous.

In various embodiments, the generation techniques being considered

may include, but are not limited to

- a triangular technique, and

- a quadrilateral technique.

Further, in various embodiments, the triangular technique is selected if, all of the above enumerated conditions are met, else the quadrilateral technique is selected.

Upon selecting the generation technique, weld bead modeling function

5   **114** proceeds to generate the fillet weld bead, block **406**.

Referring now to **Fig. 5**, wherein one embodiment of the operational flow of the triangular technique is illustrated. As shown, for the embodiment, weld bead modeling function **114** first assigns shape manager attributes to the

10   selected faces (FS1 and FS2), block **502**. In various embodiments, the attributes specify, among other things, the attributes are to be propagated whenever a split, copy or merge operation is performed on each of the selected edges. More specifically, the split, copy and merge behaviors are specified such that, during a split or copy operation, which results in an old

15   entity and a new entity, a copy of the attribute on the old entity propagates itself to the newly formed entity. During a merge operation of two entities, all the original attributes from the two entities are retained on the merged entity.

Further, in various embodiments, the attributes include information that allows various aspects of the split, copied or merged versions to be tracked

20   back to the original selected faces.

Note that all operations performed, including any split, copy or merge operations, in substance are performed on data representations **122** of the faces of the components by shape manager **116**. For ease of understanding, further description may not be burdened with the repeated clarification.

25   However, the description should be so read, unless the context clearly indicates otherwise.

Still referring to **Fig. 5**, at block **504**, weld bead modeling function **114** generates a blank (B) and a path (P). In various embodiments, the blank is

generated based at least in part on the selected faces of the selected

components, and the path is generated, based at least in part on the blank.

Thereafter, weld bead modeling function **114** determines if, the path is

open, block **506**. If the path is not open, weld bead modeling function **114**

5   proceeds to perform the operations of block **510**, however, if the path is open,

weld bead modeling function **114** first generates a trimmer body, block **508**,

before proceeding to perform the operations of block **510**.

At block **510**, weld bead modeling function **114** generates a triangular

profile (TP) **602**, by calling a shape manager API, an example of which is

10   illustrated in **Fig. 6**. The side edges **604a** and **604b** of triangular profile **602**

coincident with the selected faces are referred to as the "legs", L1 and L2.

The hypotenuse **606** is referred to as the top segment (TS).

In various embodiments, the triangular profile **602** is generated in a

plane perpendicular to the path at the starting point of the path. If the path is

15   open, the starting point may be at either one of the end points. If a path is

closed, then the starting point may be at any arbitrary point of the path.

Referring back to **Fig. 5**, at block **512**, weld bead modeling function

114 generates a tool (T) by sweeping triangular profile **602** along the earlier

generated path. In various embodiments, weld bead modeling function **114**

20   calls shape manager **116** to generate the sweep.

At block **514**, weld bead modeling function **114** determines if, a trimmer

body was earlier generated. If a trimmer body was not generated earlier, weld

bead modeling function **114** proceeds to initialize the tool as the fillet weld

bead, more specifically, the data representation of the tool as the data

25   representation of the fillet weld bead, FWB, block **522**.

If a trimmer body was generated earlier, weld bead modeling function

114 first transfers the attributes from the edges of the profile to the lateral

faces of the tool, block **516**, and performs a selective boolean operation in

shape manager **116** on the tool and the trimmer body to trim the tool, block

518. Thereafter, weld bead modeling function **114** initializes the trimmed tool as the fillet weld bead, FWB, block **520.** More specifically, as earlier described, the initialization involves initializing the data representation of the tool as the data representation of the fillet weld bead.

5   An example of the attribute transfer operations (in the context of a quadrilateral profile) is illustrated in **Fig. 9.** The attribute transfer operations are similar, whether a triangular or a quadrilateral profile is involved.

          In various embodiments, weld bead modeling function **114** calls shape manager **116** to perform a selective boolean operation which provides a

10   topology data structure of the tool and the trimmer body with "cells" identified as being cells of the tool, the trimmer body, or both. In various embodiments, weld bead modeling function **114** calls shape manager 116 to perform the boolean operation by selecting only "tool-only" cells whose faces satisfy the following:

15   at least one unique face has a L1 attribute,

                at least one unique face has a L2 attribute, and

                at least one unique face has a TS attribute.

          A number of earlier described aspects of the triangular technique, in

20   particular, the generation of a blank, a path, and a trimmer body, will be further described later, after an overview description of the quadrilateral technique.

          Referring now to **Fig. 7,** wherein one embodiment of the operational

25   flow of the quadrilateral technique is illustrated. As shown, for the embodiment, the initial operations are similar to the earlier described triangular technique. That is, weld bead modeling function **114** first assigns shape manager attributes to the selected faces, block **702.** Then, weld bead modeling function **114** generates a blank (B), based at least in part on the

selected faces of the selected components, and generates a path (P), based at least in part on the generated blank, block **704**.

Thereafter, weld bead modeling function **114** determines whether the path is open, block **706**, and constructs a trimmer body, block **708**, before

5   proceeding to perform the operations of block **710**.

At block **710**, weld bead modeling function **114** generates a profile, using shape manager API, however, for the quadrilateral technique, as the name suggests, the profile is a quadrilateral profile (QP). An example quadrilateral profile **800** is illustrated in **Fig. 8**. Edge **804** extending from one

10   of the selected faces to the other is referred to as the top segment (TS), and edges **802a-802b** are referred to as the "leg" segments, L1 and L2. Edge **806** is referred to as the unwanted segment (US).

Referring back to **Fig. 7**, at block **712**, weld bead modeling function **114** generates a tool (T) by sweeping the quadrilateral profile along the path,

15   using a shape manager API, block **712**. Thereafter, weld bead modeling function **114** determines if, a trimmer body was earlier generated, block **714**.

If a trimmer body was not earlier generated, weld bead modeling function **114** performs a selective boolean operation by calling shape manager 116 API on the tool and the trimmer body to trim the tool, block **722**,

20   and upon trimming the tool, initializes the trimmed tool as the fillet weld bead, FWB, block **724**. More specifically, as earlier described, the initialization involves initializing the data representation of the tool as the data representation of the fillet weld bead.

However if, a trimmer body was earlier generated, weld bead modeling

25   function **114** first transfers attributes from edges of the profile to lateral faces of the tool, block **716**, and subtracts the blank from the tool by calling a shape manager API to generate a subtracted tool, block **718**, before proceeding to perform the operations at block **720**. As mentioned earlier, an example of the attribute transfer operations is illustrated in **Fig. 9**.

At block **720**, weld bead modeling function **114** using shape manager **116** performs a selective boolean operation on the subtracted tool and the trimmer body to trim the subtracted tool, and upon trimming the subtracted tool, initializes the trimmed subtracted tool as the fillet weld bead, FWB, block

5   **724**. More specifically, as earlier described, the initialization involves initializing the data representation of the trimmed subtracted tool as the data representation of the fillet weld bead.

In various embodiments, weld bead modeling function **114** calls shape manager **116** to provide a topology data structure of the tool and the trimmer

10   body with "cells" identified as being cells of the tool, the trimmer body, or both.

In various embodiments, weld bead modeling function **114** performing the boolean operation selects only those cells which satisfy the following:

at least one unique face has a A1 attribute,

at least one unique face has a A2 attribute,

15   at least one unique face has a TS attribute, and

none of the faces of the cell have a US attribute.

A1 and A2 attributes are ownership attributes assigned as part of the generation of the blank, to be further described below.

20   Referring now to **Fig. 10**, wherein one embodiment of the operation flow for generating a blank is illustrated. As shown, for the embodiment, weld bead modeling function **114** first assigns shape manager ownership attributes (A1 and A2) to the selected faces (FS1 and FS2) of the selected components, block **1002**. That is, the selected faces are identified as "owners" of the fillet

25   weld bead being generated. At block **1004**, weld bead modeling function **114** determines whether a triangular profile or a quadrilateral profile is employed.

If a triangular profile is employed, weld bead modeling function **114** first proceeds to perform the operations at block **1008**, otherwise, weld bead modeling function **114** assigns shape manager's unwanted attributes to all

other faces of the selected components (C1 and C2), block **1006**, before proceeding to perform the operations at block **1008**.

At block **1008**, weld bead modeling function **114** extracts and copies the bodies from the selected faces of the selected components using shape

5   manager APIs.

At block **1010**, weld bead modeling function **114** determines if, more than one body is found. If only one body was found, weld bead modeling function **114** initializes the single body as the blank, B, block **1014**.

If more than one body was found, weld bead modeling function **114**

10   unites the multiple bodies, using a shape manager API, by merging them, block **1012**, before proceeding to perform the operations of block **1014**. At block **1014**, weld bead modeling function **114** initializes the united body as the blank, B, instead.

15   Referring now to **Fig. 11**, wherein one embodiment of the operation flow for generating a path is illustrated. As shown, for the embodiment, weld bead modeling function **114** first collects a number of edges from the blank (B), block **1102**. These edges have neighboring faces containing the described ownership attributes (A1 and A2). Then, weld bead modeling

20   function **114** copies the collected edges, using a shape manager API in block **1104**.

At block **1106**, weld bead modeling function **114** determines if, more than one edge was collected and copied. If only one edge was collected and copied, weld bead modeling function **114** initializes the single edge copy as

25   the path, block **1108**. If more than one edge was collected and copied, weld bead modeling function **114** unites the copied edges, using a shape manager API and the resulting disjointed pieces are collected as paths P1, P2, ... Pn, and so forth, block **1110**.

Referring now to **Fig. 12**, wherein one embodiment of the operation flow for generating a trimmer body is illustrated. The embodiment assumes the trimmer body is generated based on an open path. Further, recall from earlier description, the trimmer body is generated, only if, the path is open.

5   As shown, for the embodiment, weld bead modeling function **114** first locates the start and end points of an open path (P), block **1202**. At block **1204**, weld bead modeling function **114** locates points on the blank (B) corresponding to the located start and end points of the path.

Then, at block **1206**, weld bead modeling function **114** locates all the

10   faces of the blank that are incident at the corresponding points. Upon locating these faces, weld bead modeling function **114** selects the located faces that are valid, block **1208**.

In various embodiments, the factors employed to determine whether a located face is invalid may include

15   - the face belongs to FS1 or FS2. The bead is generated along such faces and they do not contribute to end trimming.

- the face geometry is not supported (e.g. in one embodiment, a spline face),

- the normal of the planar faces at the start and end points are parallel

20   to the tangents of the path at the respective points, or

- the face is a duplicate.

At block **1210**, weld bead modeling function **114**, uses a shape manager API to copy the valid faces. Such valid faces are extended and made each into a body. Then, weld bead modeling function **114** unites all

25   these bodies in a non-regularized manner and initializes the united body as the trimmer body, more specifically, the data representation of the united body as the data representation of the trimmer body, block **1212**.

In various embodiments, weld bead modeling function **114** calls shape manager **116** to unite the bodies.

Thus, it can be seen from the above description, that a fillet weld bead may be efficiently modeled. Based on the facial characteristics it uses a best fit strategy to use the right technique. i.e. triangular or quadrilateral. Besides,

5   it automatically end trims the fillet weld bead when the path is open. Moreover, by virtue of the techniques employed the fillet weld bead neither interferes with the components nor leave gaps between a component and itself.

10   **Fig. 13a-13d** illustrate an example application of CAD application **112** having weld bead modeling function **114**. The example application assumes the manufacturing of an example article involving the welding of an angle iron **1302a** to base plate **1302b** (see **Fig. 13a**).

Accordingly, CAD application **112** may be employed to first facilitate

15   the selection, e.g. by a user, the 9 faces of angle iron **1302a** (7 of which, faces **1304a-1304g**, are visible, and the remaining two are located at the back of angle iron **1302a** (not visible)) and one face **1306** of base plate **1302b**, where the fillet welding is to be performed.

In response, weld bead modeling function **114** examines the facial

20   characteristics of the selected faces, and in view of the predominantly geometric characteristics, selects the triangular technique to generate the data representation of the fillet weld.

Fig. 13b illustrates the path **1312** and the triangular profile **1314** successively generated in the application of the triangular technique. Note

25   that since the path is closed, as described earlier, no trimmer body was generated.

Fig. 13c and **Fig. 13d** illustrate the resulting fillet weld bead by itself, and its application in joining angle iron **1302a** and base plate **1302b**, respectively.

Fig. 14a-14e illustrate an example application of CAD application **112**
having weld bead modeling function **114**. The example application assumes
the manufacturing of an example article involving the welding of rib **1402b** to

5   L-bracket **1402a** (see **Fig. 14a**).

Accordingly, CAD application **112** may be employed to first facilitate
the selection, e.g. by a user, single face **1404** of rib **1402b** and 2 faces,
1406a-1406b of L-bracket **1402a**, where the fillet welding is to be performed.

In response, weld bead modeling function **114** examines the

10   predominantly geometric characteristics of the selected faces, and in view of
these characteristics, selects the triangular technique to generate the data
representation of the fillet weld.

Fig. 14b illustrates the path **1412** and the triangular profile **1414**
successively generated in the application of the triangular technique. Since

15   the path is open, accordingly, trimmer body **1422** (see **Fig. 14c**) is generated.
Also illustrated in **Fig. 14c** tool **1424**, is generated as described earlier.

Fig. 14d and **Fig. 14e** illustrate the resulting fillet weld bead by itself,
and its application in joining angle iron **1402a** and base plate **1402b**,
respectively.

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Fig. 15a-15e illustrate an example application of CAD application **112**
having weld bead modeling function **114**. The example application assumes
the manufacturing of an example article involving the welding of an angled
component **1502a** to base plate **1502b** (see **Fig. 15a**).

25   Accordingly, CAD application **112** may be employed to first facilitate
the selection, e.g. by a user, 2 faces **1504a-1504b** of angled component
1502a and one face **1506** of base plate **1502b**, where the fillet welding is to
be performed.

In response, the weld bead modeling function **114** examines the predominantly geometric characteristics of the selected faces, and in view of these characteristics, selects the quadrilateral technique to generate the data representation of the fillet weld.

5   **Fig. 15b** illustrates the path **1512** and the quadrilateral profile **1514** successively generated in the application of the quadrilateral technique. Body **1522** is illustrated in **Fig. 15c**. Since the path is open, accordingly, trimmer body **1524**, illustrated in **Fig. 15d**, is generated. Also illustrated in **Fig. 15c** is tool **1526** generated as described earlier.

10   **Fig. 15e** and **Fig. 15f** illustrate the resulting fillet weld bead by itself, and its application in joining angled component **1502a** and base plate **1502b**, respectively.

Thus, it can be seen from the above descriptions, embodiments of a
15   novel method to generate fillet welds have been described. While the novel method has been described in terms of the foregoing embodiments, those skilled in the art will recognize that the method is not limited to the embodiments described. The method may be practiced with modifications and alterations within the spirit and scope of the appended claims.

20   Accordingly, the description is to be regarded as illustrative instead of restrictive.